IN-71

63207

NASA Technical Memorandum 107237
AIAA–96–1667

# Core and Fan Streams' Mixing Noise Outside the Nozzle for Subsonic Jet Engines With Internal Mixers

Naseem H. Saiyed
*Lewis Research Center*
*Cleveland, Ohio*

James E. Bridges
*NYMA, Inc.*
*Brook Park, Ohio*

Eugene A. Krejsa
*Lewis Research Center*
*Cleveland, Ohio*

Prepared for the
Second Aeroacoustics Conference
sponsored by the American Institute of Aeronautics and Astronautics
and the Confederation of European Aerospace Societies
State College, Pennsylvania, May 6–8, 1996

National Aeronautics and
Space Administration

# Core and Fan Streams' Mixing Noise Outside the Nozzle for Subsonic Jet Engines with Internal Mixers

Naseem H. Saiyed
NASA Lewis Research Center
Cleveland, Ohio

James E. Bridges
NYMA, Inc.
Brook Park, Ohio

and

Eugene A. Krejsa
NASA Lewis Research Center
Cleveland, Ohio

ABSTRACT

An experimental investigation was completed to determine the acoustic benefits of three Internal Exhaust Gas Mixers (IEGM's). The IEGM's had 12-lobes, 20-lobes and 24-lobes. Data presented is for ideally expanded jet velocities of approximately 1330 ft/sec (jet Mach number, Mj, = 1.0) and for flight Mach numbers from 0.20 to 0.27.

Acoustic data, LDV data and Schlieren images indicate the existence of a core and fan mixing region located within approximately 1.5 nozzle diameters downstream of the nozzle exit. This "residual mixing" region exists because of incomplete mixing within the nozzle. The Effective Perceived Noise Level (EPNL), an indicator of the perceived noisiness of an aircraft, is sensitive to the residual mixing frequencies. The residual mixing noise levels at these frequencies are several decibels above the simple jet noise and the IEGM's internal noise levels. The residual mixing noise seems to cause the 24-lobe IEGM's total noise to be approximately 1.5 PNdB above that predicted for a simple jet. Consequently, improvements to the IEGM's are needed to increase EPNL reductions. The improvements should be directed toward eliminating the residual mixing by completely mixing the core and fan streams within the nozzle. Once the residual mixing is eliminated, the next noise floor may be the internal noise that an acoustically lined exhaust nozzle may help reduce.

## INTRODUCTION

Aircraft noise is a major environmental concern for the world community. Many airport authorities are imposing landing fees and other restrictions based on aircraft noise levels. These actions are attempts to reduce the aircraft noise impact on communities near their airports. NASA has initiated a major noise reduction effort, the Advanced Subsonic Transport Program (AST), to address this issue. A significant portion of the program addresses the noise issue from the aircrafts' turbofan engines [Stephens and Cazier, 1995].

As part of the AST, the NASA Lewis Research Center is developing techniques for future engines that will meet more stringent noise rules. However, penetration of new engines into the market significantly lags their initial introduction. Therefore, development of noise reduction techniques for existing engines is critical for reducing noise from the total aircraft fleet.

Fan noise and jet noise are two main noise sources from a turbofan engine. Engine cycle defines the relative importance of these sources toward total engine noise. Jet noise is the dominant noise source for low bypass ratio engines, and fan noise is the dominant source for high bypass ratio engines. However, advances in the fan noise reduction techniques and (or) upgrading of the engines (throttle push) increase the significance of the jet noise toward the total noise from high bypass ratio engines.

A turbofan engine produces thrust by exhausting the core (turbine) flow and the fan (bypass) flow through an exhaust system that uses either separate-flow nozzles or a common-flow nozzle. In separate-flow nozzles, the core flow and the fan flow are separated from each other and exit the engine through their individual nozzles. In the common-flow nozzle, on the other hand, the core flow and the fan flow exit the engine through a common nozzle. Again, the engine cycle defines the use of separate-flow or common-flow nozzle exhaust system.

The jet noise from separate-flow nozzles or common-flow nozzle is highly dependent on the jet exhaust velocity. Subsonic jet noise intensity, I, follows the relation [see for example, von Glahn, et al. 1973]:

$$I \propto \left(V_j - V_o\right)^6 V_j^2$$

where $V_j$ is the ideally expanded jet velocity from the exhaust nozzle and $V_o$ is the aircraft flight speed. Methods to reduce $V_j$ without incurring significant thrust reduction are highly desirable.

An Internal Exhaust Gas Mixer (IEGM) is a device to reduce $V_j$ without significant thrust penalties for the turbofan engines using common-flow nozzles [see for example, Barber, et al., Part I, II and III, 1988]. The IEGM's increase the surface area of the shear layer between the core and fan streams, and create large scale vorticity to increase the core and fan mixing.

As part of the turbofan engine jet noise reduction efforts with the U.S. industry, NASA Lewis initiated a three year research and technology program to develop and demonstrate jet noise reduction concepts for turbofan engines using IEGM's. The program goal is to develop the IEGM technique to reduce the jet noise by 3 EPNdB (Effective Perceive Noise decibels) by 1996. The goal was set relative to the state of the art at the initiation of this effort in 1993. As part of the effort, the experimental data would be used to calibrate the Computational Fluid Dynamics (CFD) and Computational Aeroacoustic Analysis (CAA) codes.

An experiment was completed in 1994 on several IEGM's to investigate the impact of their design on jet noise and on the flow field as the first phase of this effort. The impact of IEGM design on Effective Perceived Noise Levels (EPNLs) were determined [Montuori and Saiyed, 1995]. Laser Doppler Velocimetry (LDV) data were also acquired using the LDV system described by Podboy [Podboy, et al. 1995] and compared with CFD codes [Zysman, et al. 1995]. Lastly, applicability of CAA codes to IEGMs was also reported [Barber, et al. 1996].

This report is concerned with the reduction of jet noise from turbofan engines using IEGM's. For the purposes of this report, a "simple jet" is a fully expanded jet from a round convergent nozzle. The IEGM spectra show that the Sound Pressure Levels (SPL) at low frequency were nearly identical with what may be expected from simple jets, but at intermediate to high frequencies the IEGM data significantly differed from the simple jet expectation. This discrepancy was investigated. The results of the investigation are presented here and an explanation for the discrepancy is proposed.

## OBJECTIVES

Analyses of the acoustic results showed a frequency-dependent discrepancy between the IEGM data and the expected data for a simple jet. An attempt was undertaken to investigate the source of the discrepancy and to assess its acoustic impact on the IEGM's total noise. This report presents the findings and provides supplemental flow data supporting the acoustic results.

## TEST HARDWARE and FACILITY SPECIFICATIONS

All tests were conducted at NASA Lewis' Aeroacoustic and Propulsion Lab (APL). Castner [1994] and Cooper [1993] provide the APL details and its acoustic environment, respectively. Since Cooper's report, the APL was upgraded with acoustically treated wedges on the floor to make the facility fully anechoic.

These tests were conducted using three 1/7th scale IEGM's. Figure 1a shows a perspective view of the 12-lobe IEGM as installed within the nozzle. The lobe spacing is 0.60". The lobe spacing for the 20-lobe and 24-lobe IEGM's are 0.37" and 0.29", respectively. The IEGM exit plane areas are 12.5 $in^2$ and 21 $in^2$ for the core and fan flows, respectively. The nozzle exit plane area is 22.6 $in^2$.

Figure 1b shows a cross-section of the NASA Lewis' Jet Exit Rig (JER) with the IEGM installed. The JER can simulate a range of jet engine operating cycles up to 60 psia on the fan and core streams. The maximum temperature limit for the core stream is 2000 R. Forward flight is simulated with a free jet. The free jet is a 53" round duct capable of up to 0.30 flight Mach number ($M_o$). A contraction, with a 7° contraction angle, is used to reduce the boundary layer on the JER. The contraction reduces the 53" duct to 40".

## ACOUSTIC DATA

Acoustic data were acquired using 1/4" Bruel and Kjaer microphones. The microphones were positioned on a 48 foot radius from the nozzle exit in a horizontal plane through the nozzle axis. The microphones were spaced at 5° interval from 45° (forward arc) to 165° (aft arc). The nozzle center and the microphones were located 10 feet above the ground. The measured spectra were corrected for microphone calibration, atmospheric absorption, and spherical spreading to bring the data to 1-foot lossless conditions. Finally, these spectra were extrapolated to full-scale values at 150 foot radius at 70° F and 77% relative humidity. The extrapolation included Doppler flight effects. The data were also extrapolated to 1500' flyover altitude for evaluation of EPNL.

## RESULTS AND DISCUSSION

Figure 2 presents one-third octave SPL spectra for the 12-lobe IEGM at 70°, 90° and 120°. These data are for fully mixed and ideally expanded velocity of 1315 ft/sec (jet Mach number, Mj, of 1.0) at $M_o$ of 0.27. Calculated velocity at the core mixer exit plane was 850 ft/sec and for the fan 430 ft/sec. Also shown in the same figure is the prediction for an ideally expanded simple jet [Stone, 1974]. The predictions are adjusted only slightly (+/- 1 dB or +/- one 1/3 octave band) at each angle to better fit the low-frequency spectra. With the slight adjustment, the IEGM total SPL match the simple jet predictions well at the low frequencies. However, IEGM total SPL at intermediate to high frequencies are always greater than the prediction—this occurred with or without the aforementioned slight adjustment. The IEGM's total noise is equal to, or slightly greater than, a simple jet's self-noise in the forward arc. In the aft arc, the IEGM total noise is greater than a simple jet's self-noise at mid to high frequencies.

The impact of lobe count on the IEGM total noise will be published in a separate report. The same trend exists for all mixers. Apparently, sources other than a simple jet's self-noise are contributing to the total IEGM noise measured at intermediate to high frequencies.

The difference between the flow outside the nozzle from these IEGM's and Stone's simple jet is that the IEGM's have high velocity streaks which are remnants of the flow through the internal mixer lobes. The streaks are the origin of a third noise source in addition to the IEGM internal mixing noise and the fully expanded jet noise. The purpose of an IEGM is to mix the flow uniformly and quickly within the nozzle. The lobes of the IEGM interleave core and fan streams and create two counter-rotating vortices from each lobe to promote mixing. If not dissipated within the IEGM mixing chamber, these vortices continue outside the nozzle. Their mixing outside the nozzle is called residual mixing.

All IEGM's had the residual mixing. Figure 3 shows focused Schlieren images of the flow fields downstream of the nozzle exit for the three IEGM's. The arrows indicate the location of the lobe. The focusing plane is parallel to the jet axis and focused on the nozzle centerline. The 12-lobe mixer has the clearest and largest streaks. For the 20 and 24-lobe mixers, the streaks become thinner and are not as far apart. For all mixers, the streaks persist atleast one nozzle diameter, the field of view of the Schlieren system.

Axial velocity and vorticity data obtained using LDV on the 12 and 20 lobe IEGM's at the nozzle exit plane are shown in Figures 4a and Figure 4b, respectively. Velocity is in ft/sec and vorticity is in rad/sec. For the 12-lobe IEGM, a high velocity spot exists for each lobe. The 12-lobe IEGM vorticity plot shows that two counter-rotating vortices are present for each lobe. The vortices fill the circumference making their width equal to one-half the lobe spacing. Axial velocity is greatest between a lobe's vortices. The 20-lobe data show that instead of a high velocity spot, an annular high velocity region exists. The 20-lobe vorticity plot also shows counter-rotating vortices of size equal to one-half of the lobe spacing. Although the intention of increasing the IEGM lobe count is to smear out high velocity regions, appreciable mixing enhancement does not occur. The 20-lobe IEGM vorticity is nearly as strong as the 12-lobe IEGM vorticity, and instead of achieving uniform velocity at the nozzle exit plane, a high velocity annular ring is formed.

Let us look at the acoustic impact of residual mixing for the 24-lobe IEGM. Figure 5a shows the spectra for this IEGM at 90° for various free jet Mach numbers. The predicted flight benefit at this angle is approximately 2 dB between 0.20 and 0.27 $M_o$ with $V_j$ of 1315 ft/sec. At the low frequencies, this benefit is realized. However, through the intermediate frequencies the flight benefit continuously decreases and eventually disappears above 2.5kHz (Strouhal number based on jet diameter ($St_j \approx 6$)). This suggests that the noise above 2.5kHz is independent of flight speed, and, therefore, this noise is probably generated inside the nozzle.

Since IEGM's internal noise is independent of the $M_o$, shape of the 90° spectra is expected in the forward and aft arcs. Figure 5b shows the one-third octave spectra at 70° and 120°, respectively. The spectra at the low frequencies show the flight benefit. A remarkable difference is seen between the 90° spectra and these spectra at the high frequencies: SPL at high frequencies in the forward and aft arcs are dependent on flight speed! This noise is not the jet self-noise because the SPL are much higher than those predicted for a simple jet. Nor is the difference seen due to convective amplification of the internal noise [Ahuja, et al., 1978]:

$$\Delta\, dB_{ca} = -\,40 \log\left(1 - M_o \cos\theta\right)$$

where $\theta$ is the angle measured from the inlet axis, and $\Delta dB_{ca}$ is the convective amplification. Figure 6 shows the results after the 70° and 120° data were corrected for $\Delta dB_{ca}$. Table 1 shows the $\Delta dB_{ca}$ values. Similar trends are observed for the 12-lobe and the 20-lobe IEGMs, but they occur at much lower jet velocity. Since flight speed has an impact on the SPL at all frequencies, we infer that the source of this noise is external to the nozzle. Also, the internal noise does not make a significant contribution in determining the IEGM's total noise. The reason for the flight benefit disappearing at 90° is not yet clear.

The above discussion has established that if IEGMs do not completely mix the core and fan flows prior to reaching the common-flow nozzle exit, a high intensity residual mixing region is created. The residual mixing region lasts atleast 1 to 1.5 nozzle diameters downstream of the nozzle exit. The residual mixing creates noise in the intermediate to high frequencies. The SPL's at these frequencies are nearly those associated with the fully expanded jet at low frequencies. The impact of residual mixing noise on the 24-lobe IEGM's Perceived Noise Level (PNL) directivity is compared with the PNL directivity predicted for a simple jet in Figure 7. The 24-lobe IEGM's peak PNL is nearly 1.5 dB's above the peak PNL predicted for a simple jet. The 12-lobe IEGM's PNL directivity was greater than that of the 24-lobe IEGM's.

The impact of eliminating the residual mixing on the PNL, and therefore on the EPNL, is clear. This assumes that in eliminating the residual mixing, the IEGM's internal noise remains an insignificant contributor toward the IEGM's total noise. At this point of IEGM technique development, acoustic liners for the IEGM's are not likely to provide attractive EPNL benefits because the dominant noise source is outside the nozzle.

## CONCLUDING REMARKS

NASA, in partnership with industry, continues to develop new techniques for quieter aircraft. In this test program, three low-bypass ratio IEGMs (12-lobe, 20-lobe and 24-lobe) were tested to determine their noise characteristics. The mixers differed in lobe count only with the corresponding variation in their lobe widths. The total cross-sectional area for the core and the fan flows remained nearly constant. Each mixer was tested statically and at 0.2, 0.23 and 0.27 flight Mach numbers. Data is presented for fully mixed and ideally expanded jet velocity of approximately 1330 ft/sec with the core and fan exit plane velocities of approximately 850 ft/sec and 430 ft/sec, respectively.

Acoustics, LDV and Schlieren data were acquired. These data show the existence of a residual mixing region downstream of the common-flow nozzle exit—a region where fan and core mixing is completed. Physically, this region may be found within 1 to 1.5 jet diameters downstream of the nozzle exit. At the current level of IEGM development, this noise source dominates the EPNL calculations due to the frequencies and SPL involved. Lastly, because the real noise floor is the external residual mixing noise, EPNL benefits from acoustic liners will be limited until the internal noise becomes a significant contributor to the IEGM's total noise.

## ACKNOWLEDGEMENT

The authors thank Mr. Ron P. Foster and Mr. Tom A. Ralys of NASA Lewis' Wind Tunnels and Aircraft Components Branch of Test Installations Division, and Mr. Ray S. Castner of Engine Components Branch of Aeropropulsion Facilities and Experiments Division for their immense patience and untiring support throughout the testing phase of this program.

## REFERENCES

Ahuja, K. K.; Tester, B. J and Tanna, H. K., "The Free Jet as a Simulator of Forward Velocity Effects on Jet Noise", NASA Contractor Report 3056, Contract number NAS3-20050, October 1978

Barber, T. J.; Chiappetta, L. M.; Zysman, S. H.; " An Assessment of Jet Noise Analyses for Multistream Axisymmetric and Mixer Nozzles", 34th Aerospace Sciences Meeting, Reno, NV, January 15-18, 1996

Barber, T.; Paterson, R. W.; and Skebe, S. A.; "Turbofan Forced Mixer Lobe Flow Modeling, I—Experimental and Analytical Assessment", NAS3-23039, NASA CR 4147, Part I, 1988

Barber, T. "Turbofan Forced Mixer Lobe Flow Modeling, II—Three-Dimensional Inviscid Mixer Analysis (FLOMIX)", NAS3-23039, NASA CR 4147, Part II, 1988

Barber, T., Moore, G. C. and Blatt, J. R.; "Turbofan Forced Mixer Lobe Flow Modeling, III—Application to Augment Engines", NAS3-23039, NASA CR 4147, Part III, 1988

Castner, R. S.; "The Nozzle Acoustic Test Rig: An Acoustic and Aerodynamic Free-Jet Facility", NASA TM 106495, 1994

Cooper, Beth A.; "A Large Hemi-Anechoic Enclosure for Community-Compatible Aeroacoustic Testing of Aircraft Propulsion Systems", NASA TM 106015, April 1993

Lilly, G. M., "On the Noise from Air Jets", British Aerospace Research Council Rep. ARC-20, 376; N 40; FM-2724, September 1958

Montuori, P. and Saiyed, N.; "Improved internal Exhaust Gas Mixers", Inter-Noise '95, Newport Beach, CA, July 10-12, 1995

Podboy, G. G.; Bridges, J. E.; .Saiyed, N. H. and Krupar, M. J.; "Laser Doppler Velocimetry for a subsonic jet mixer nozzle at the NASA Lewis Aero/Acoustic/Propulsion Lab", 31st JPC, San Diego, CA, July 10-12, 1995

Stephens, David G. and Cazier F. W. Jr.; "NASA Noise Reduction Program for Advanced Subsonic Transports"; Inter-Noise '95, Newport Beach, CA, July 10-12, 1995

Stone, James, R.; "Interim Prediction Method for Jet Noise", NASA TMX-71618, 1974

von Glahn U.; Groesbeck, D.and Goodykoontz, J.; "Velocity Decay and Acoustic Characteristics of Various Nozzle Geometries with Forward Velocity", AIAA paper 73-629, July 1973

Zysman, S. H.; Chiappetta, L. M.; Saiyed, N. H. and Podboy, G. G.; "Flow field measurement and analysis of a 1/7th scale mixed flow exhaust system model", 31st JPC, San Diego, CA, July 10-12, 1995

| θ | M = 0.27 | Mo = 0.24 | Mo = 0.23 | Mo = 0.2 |
|---|---|---|---|---|
| 55° | 2.976 | 2.571 | 2.429 | 2.165 |
| 60° | 2.564 | 2.219 | 2.098 | 1.871 |
| 65° | 2.142 | 1.856 | 1.756 | 1.568 |
| 70° | 1.712 | 1.487 | 1.407 | 1.258 |
| 75° | 1.280 | 1.113 | 1.054 | 0.944 |
| 80° | 0.848 | 0.739 | 0.700 | 0.627 |
| 85° | 0.421 | 0.367 | 0.348 | 0.312 |
| 90° | 0.000 | 0.000 | 0.000 | 0.000 |
| 95° | -0.411 | -0.359 | -0.341 | -0.307 |
| 100° | -0.809 | -0.709 | -0.673 | -0.605 |
| 105° | -1.192 | -1.046 | -0.994 | -0.895 |
| 110° | -1.559 | -1.369 | -1.302 | -1.173 |
| 115° | -1.906 | -1.677 | -1.595 | -1.438 |
| 120° | -2.234 | -1.967 | -1.872 | -1.689 |
| 125° | -2.540 | -2.239 | -2.131 | -1.925 |
| 130° | -2.823 | -2.490 | -2.371 | -2.143 |
| 135° | -3.081 | -2.721 | -2.591 | -2.344 |
| 140° | -3.315 | -2.930 | -2.791 | -2.525 |
| 145° | -3.523 | -3.116 | -2.969 | -2.687 |
| 150° | -3.705 | -3.278 | -3.124 | -2.829 |

Table 1: Convective Amplification of Internal Noise

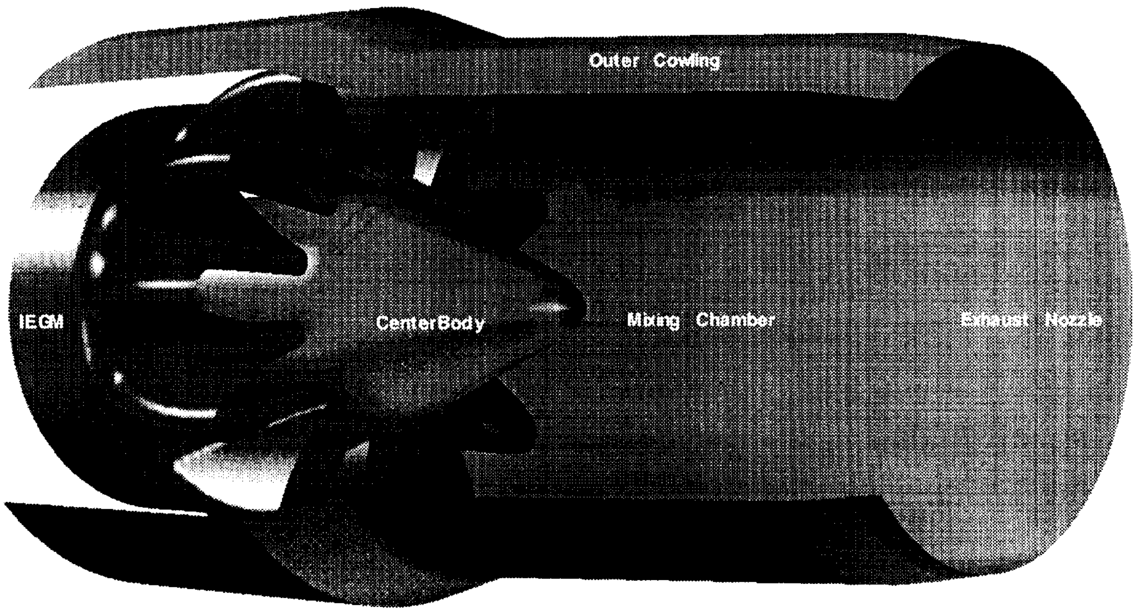



Figure 1a: 12-lobe IEGM with Nozzle

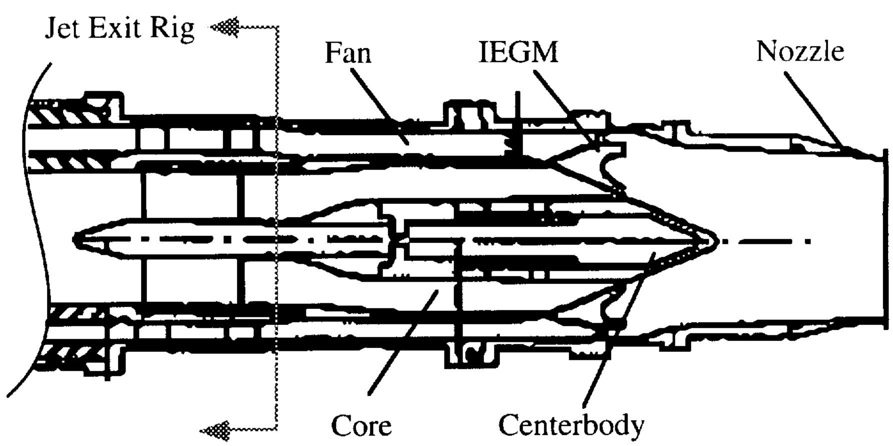



Figure 1b: Cross-section of IEGM installation in the JER

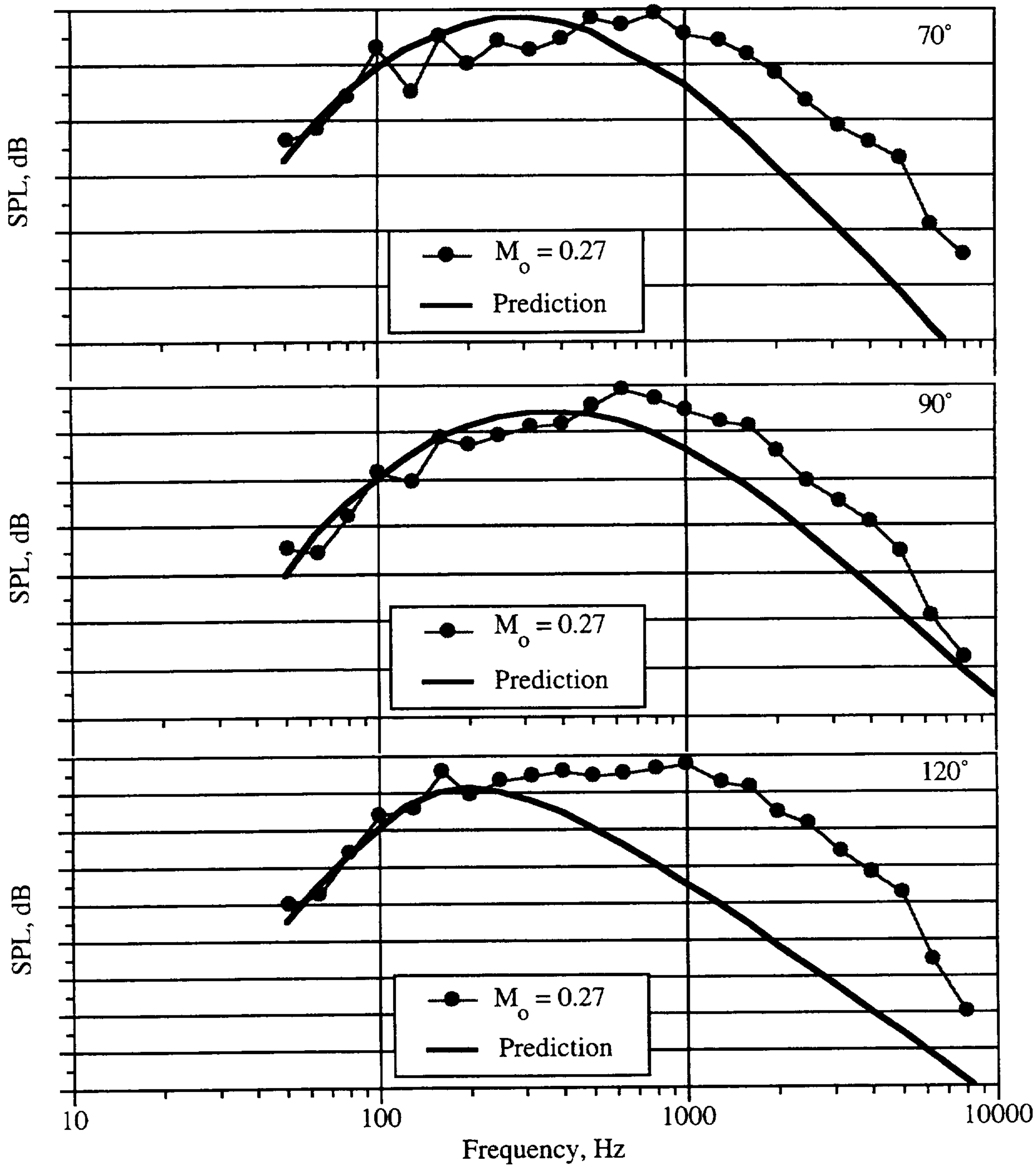
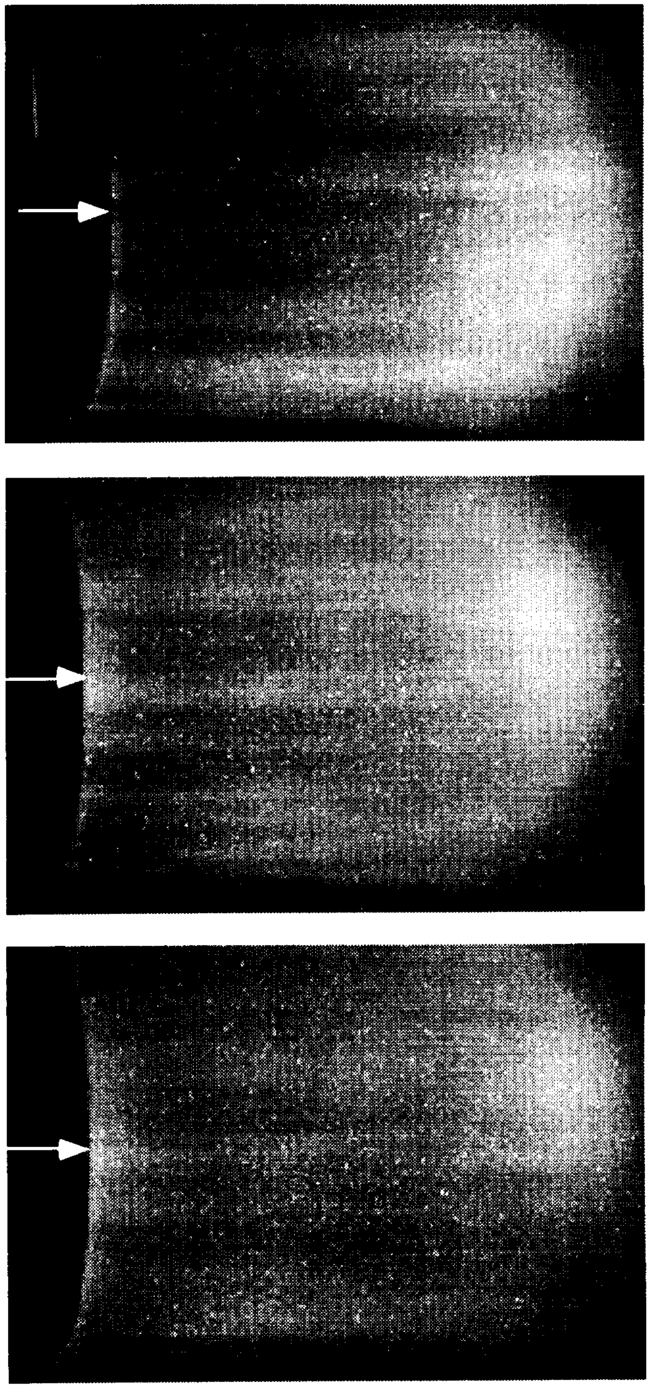



Figure 2: 12-lobe IEGM spectra comparison with the simple jet prediction

Note: Ordinate increment is 2 dB (subsidivions are 1 dB). Predictions are for a simple jet.



12-lobe IEGM

20-lobe IEGM

24-lobe IEGM

Figure 3: Schlieren images of the three IEGMs

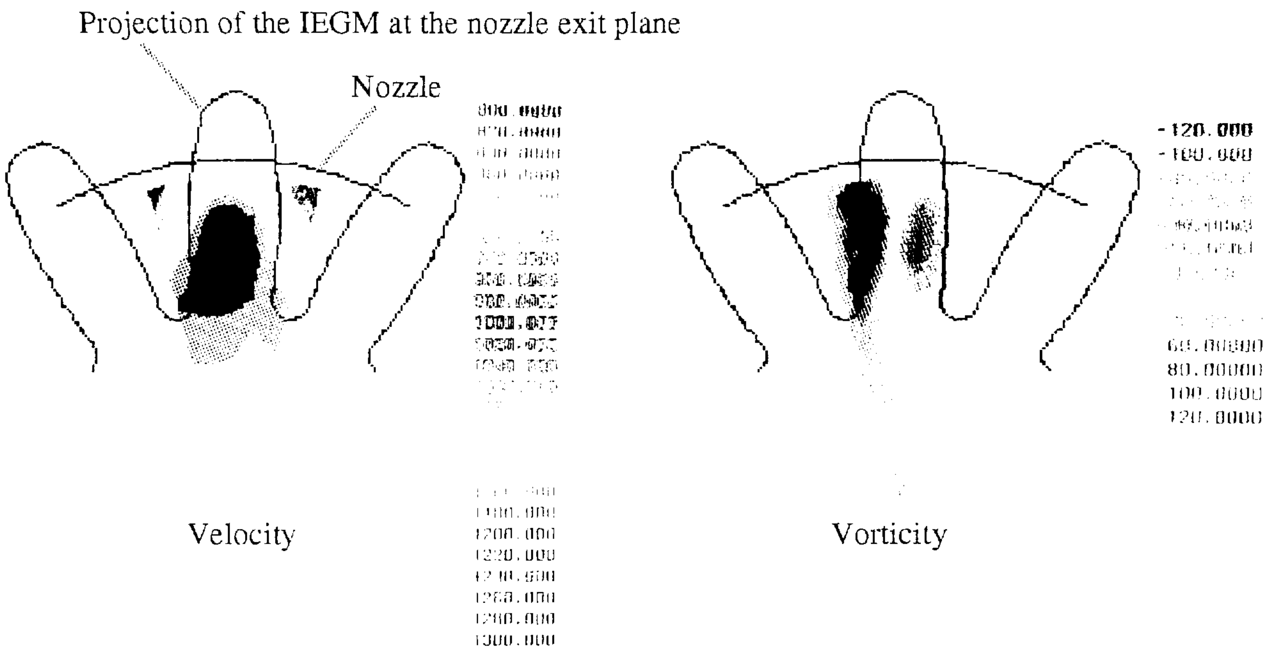



Figure 4a: 12-lobe Velocity and Vorticity at the Nozzle Exit Plane

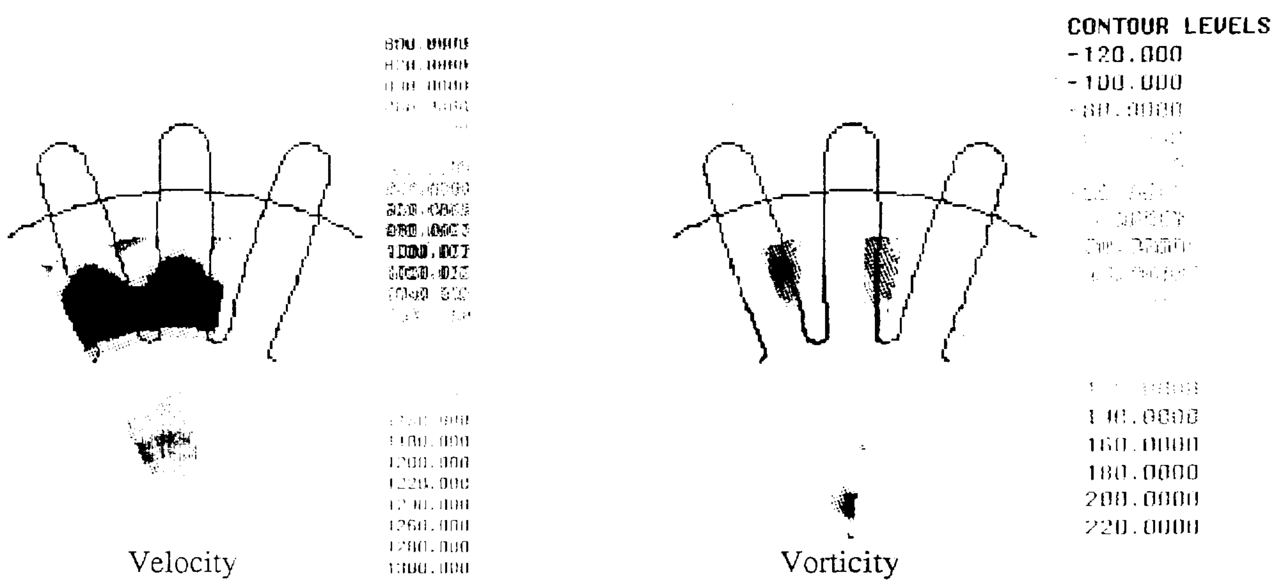



Figure 4b: 20-lobe Velocity and Vorticity at the Nozzle exit plane

Figure 5a

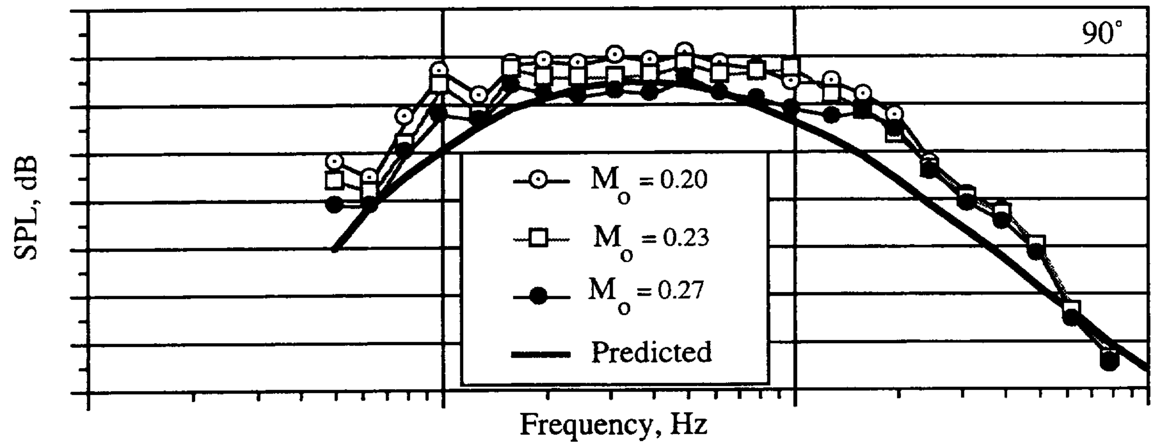



Figure 5b

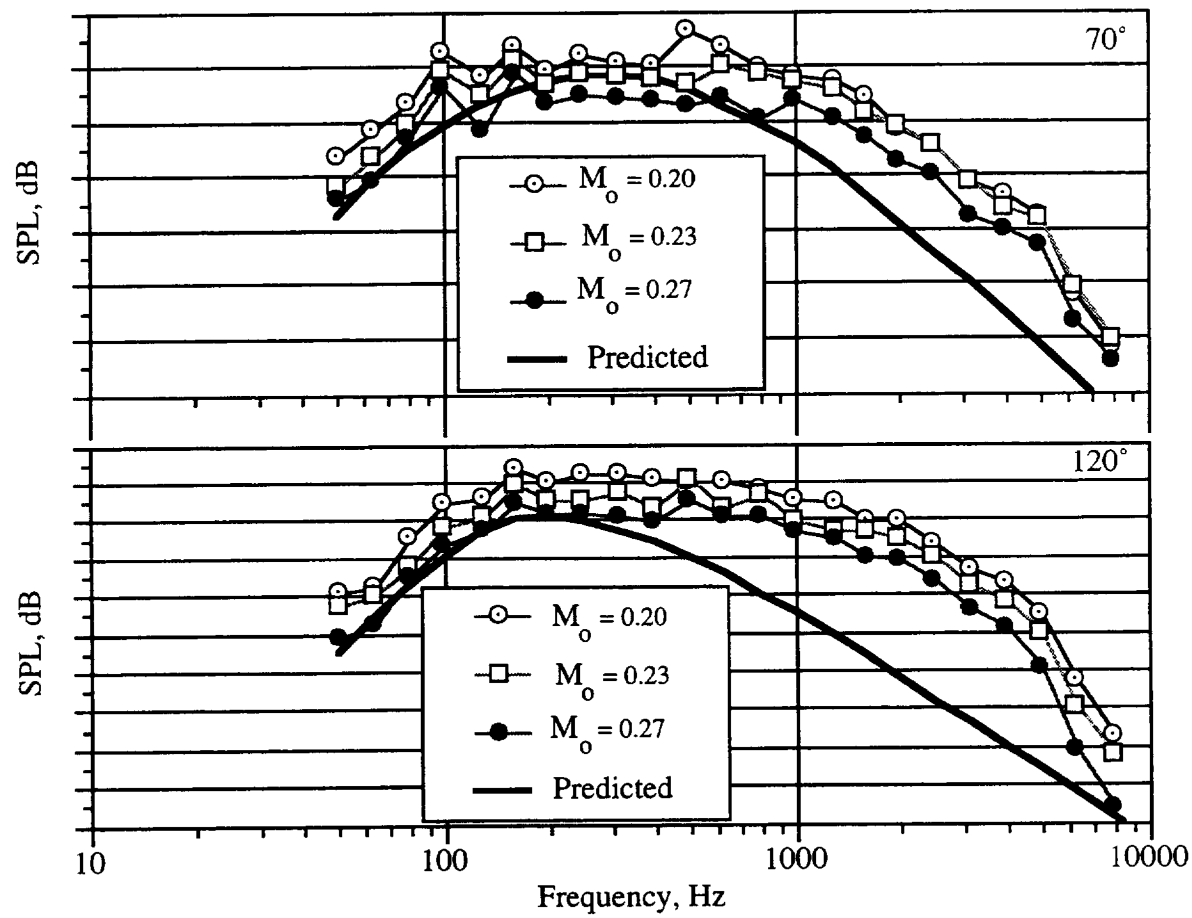



Figure 5. Flight effect on the 24-lobe IEGM and the predicted simple jet at $M_o = 0.27$

Note: Ordinate increment is 2 dB (subdivisions are1 dB). Predictions are for a simple jet.

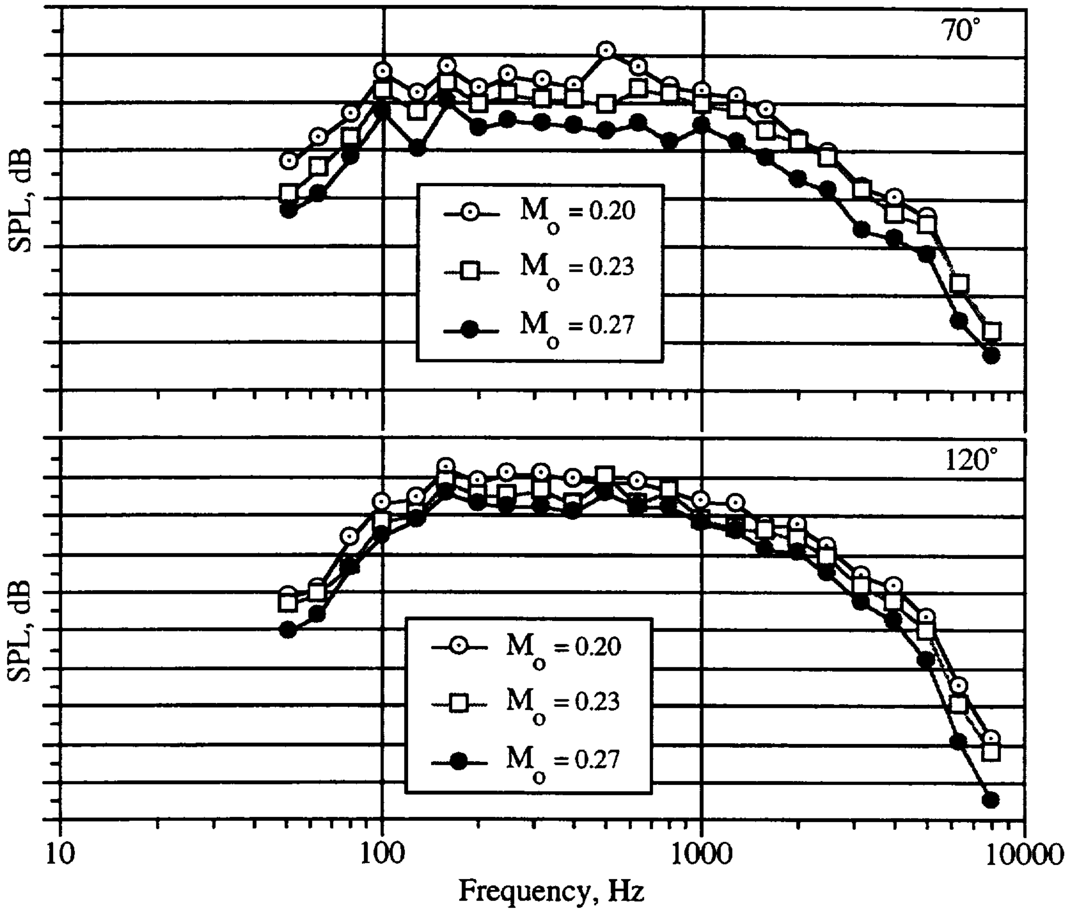



Figure 6: 24-lobe IEGM spectra after convective amplification correction

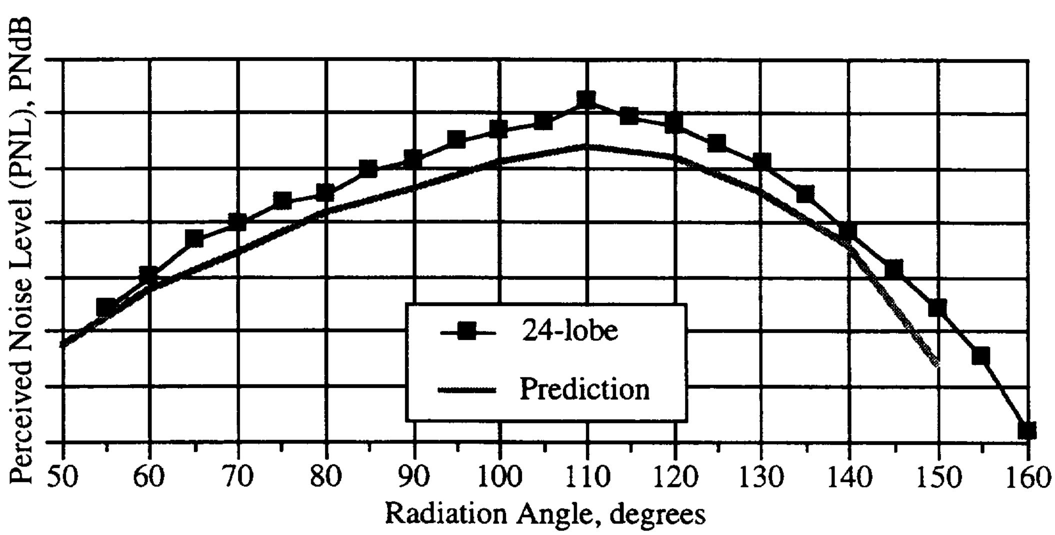



Figure 7: 24-lobe IEGM PNL directivity compared with predicted for simple jet

Note: Ordinate increment is 2 dB. Predictions are for a simple jet.

# REPORT DOCUMENTATION PAGE

*Form Approved*
*OMB No. 0704-0188*



**1. AGENCY USE ONLY** *(Leave blank)*

**2. REPORT DATE**
June 1996

**3. REPORT TYPE AND DATES COVERED**
Technical Memorandum

**4. TITLE AND SUBTITLE**
Core and Fan Streams' Mixing Noise Outside the Nozzle for Subsonic Jet Engines With Internal Mixers

**5. FUNDING NUMBERS**
WU–538–03–11

**6. AUTHOR(S)**
Naseem H. Saiyed, James E. Bridges, and Eugene A. Krejsa

**7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)**
National Aeronautics and Space Administration
Lewis Research Center
Cleveland, Ohio 44135–3191

**8. PERFORMING ORGANIZATION REPORT NUMBER**
E–10281

**9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)**
National Aeronautics and Space Administration
Washington, D.C. 20546–0001

**10. SPONSORING/MONITORING AGENCY REPORT NUMBER**
NASA TM–107237
AIAA–96–1667

**11. SUPPLEMENTARY NOTES**
Prepared for the Second Aeroacoustics Conference sponsored by the American Institute of Aeronautics and Astronautics and the Confederation of European Aerospace Societies, State College, Pennsylvania, May 6–8, 1996. Naseem H. Saiyed and Eugene A. Krejsa, NASA Lewis Research Center; James E. Bridges, NYMA, Inc., 2001 Aerospace Parkway, Brook Park, Ohio 44142 (work funded by NASA Contract NAS3-27186). Responsible person, Naseem H. Saiyed, organization code 2770, (216) 433–6736.

**12a. DISTRIBUTION/AVAILABILITY STATEMENT**
Unclassified - Unlimited
Subject Category 71

This publication is available from the NASA Center for AeroSpace Information, (301) 621–0390.

**12b. DISTRIBUTION CODE**

**13. ABSTRACT** ***(Maximum 200 words)***
An experimental investigation was completed to determine the acoustic benefits of three Internal Exhaust Gas Mixers (IEGM's). The IEGM's had 12–lobes, 20–lobes, and 24–lobes. Data presented is for ideally expanded jet velocities of approximately 1330 ft/sec (jet Mach number, Mj = 1.0) and for flight Mach numbers from 0.20 to 0.27. Acoustic data, LDV data and Schlieren images indicate the existence of a core and fan mixing region located within approximately 1.5 nozzle diameters downstream of the nozzle exit. This "residual mixing" region exists because of incomplete mixing within the nozzle. The Effective Perceived Noise Level (EPNL), an indicator of the perceived noisiness of an aircraft, is sensitive to the residual mixing frequencies. The residual mixing noise levels at these frequencies are several decibels above the simple jet noise and the IEGM's internal noise levels. The residual mixing noise seems to cause the 24–lobe IEGM's total noise to be approximately 1.5 PNdB above that predicted for a simple jet. Consequently, improvements to the IEGM's are needed to increase EPNL reductions. The improvements should be directed toward eliminating the residual mixing by completely mixing the core and fan streams within the nozzle. Once the residual mixing is eliminated, the next noise floor may be the internal noise that an acoustically lined exhaust nozzle may help reduce.

**14. SUBJECT TERMS**
Aeroacoustics; Internal mixers; Noise; Acoustics; Nozzle; Jet noise; Jet engines; Mixing noise

**15. NUMBER OF PAGES**
16

**16. PRICE CODE**
A03

| 17. SECURITY CLASSIFICATION OF REPORT | 18. SECURITY CLASSIFICATION OF THIS PAGE | 19. SECURITY CLASSIFICATION OF ABSTRACT | 20. LIMITATION OF ABSTRACT |
|---|---|---|---|
| Unclassified | Unclassified | Unclassified | |